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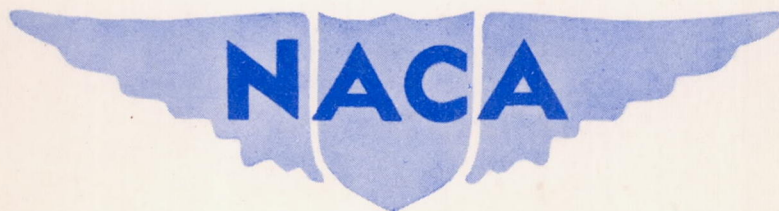
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A PROPOSED METHOD OF MEASURING ENGINE CHARGE

AIR FLOW IN FLIGHT

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NACA

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SUMMARY

A method is outlined for determining in flight the weight rate of air flow to the engine equipped with a Bendix-Stromberg injection-type carburetor. The method has the advantages that no additional equipment need be inserted in the charge-air system and only a few simple measurements are necessary. The analysis of an air-box calibration of the carburetor to be used in interpreting the flight measurements is shown by an example.

INTRODUCTION

Much difficulty has been experienced in measuring the weight rate of air flow to the engine in flight in order to determine fuel-air ratio or to investigate other phases of engine operation. When it is possible to insert an orifice plate or a Venturi in the induction system, additional losses are introduced in the system. Pitot-static traverses with a reasonable number of tubes do not usually define the velocity distribution with sufficient accuracy and, in some cases, are largely affected by turbulence. It has been found that, on airplanes equipped with the Bendix-Stromberg injection-type carburetor, charge air flow can be determined accurately within certain limits with a few relatively simple measurements. The method of interpreting these measurements is outlined herein.

METHOD

The air-measuring unit of the Bendix-Stromberg injection-type carburetor consists of a double Venturi

Figure 2 shows a typical air-flow calibration of a Bendix-Stromberg injection-type carburetor plotted according to the generalized equation (1). Data plotted in figure 2 include air-box tests at ordinary room temperature at the inlet obtained from Bendix Aviation Corp. Stromberg Aviation Carburetor Dept. and Wright Field air-box tests both at room temperature and at approximately -40° F at the inlet (reference 1). Analyzed in this way, the characteristics of the Venturi system can be simply determined because only the range of pressure ratio need be investigated; that is, it is unnecessary to simulate temperatures or all possible combinations of density and air flow. Figure 3 illustrates better than figure 2 that the calibration is independent of temperature, when the data are analyzed in this manner. In figure 3(a) some of the data included in figure 2 are shown in the usual presentation as the pressure difference developed by the Venturi system for a range of entrance density at a constant air flow. For a given entrance density, the pressure difference varies with the temperature. In figure 3(b) the same data are plotted in the manner suggested by equation (1) and figure 2. The temperature effect disappears, and the relation between pressure ratio and the variable $W^2/2g^2\rho_1 H_1$ is shown to be independent of the temperature. The characteristics of the Venturi system can therefore be established by calibration tests at any desired temperature and can be specified by a single curve of the air-flow parameter $W^2/2g^2\rho_1 H_1$ throughout the desired range of pressure ratio.

ACCURACY

The experimental deviation of the measurement of air flow by the method outlined herein is within $\pm 1\frac{1}{2}$ percent for values of pressure ratio greater than 0.65. This deviation is shown in figure 4, where the percentage deviation of the factor $W^2/2g^2\rho_1 H_1$ from the faired curve of figure 2 is plotted against the pressure ratio. Except at high pressure ratios for which the low pressure differences could not be read from the calibration curves with sufficient accuracy, scatter of the data in the square of the air flow is of the order of ± 3 percent,

or in the air flow is of the order of $\pm 1\frac{1}{2}$ percent. This
scatter is the same order of accuracy usually achieved
in the determination of the air flow with the calibrating
equipment used.

At pressure ratios less than 0.65, the scatter of
the data increases until at a pressure ratio of approxi-
mately 0.40 the Venturi system becomes worthless as a
measuring unit. Figure 2 shows that the minimum pres-
sure ratio obtainable is approximately 0.40. Because
theory indicates that pressure ratios less than 0.528 can
be attained only in supersonic flow in an increasing
area, the point of measurement in the boost Venturi is
probably somewhat downstream of the effective throat of
the Venturi. Theory further indicates that, for the
relative areas necessary to satisfy the foregoing condi-
tions, a pressure ratio of approximately 0.65 will be
attained at the point of measurement when the speed of
sound is just reached at the throat of the boost Venturi.
The definite change in the character of carburetor cali-
bration below a pressure ratio of 0.65 corresponds
to the transition from subsonic to supersonic flow in
the Venturi. It is evident from figure 4 that the flow
in the boost Venturi cannot be definitely controlled
under this condition and the accuracy of the unit as an
air-flow measuring device is lessened.

According to reference 2, large changes in pressure
distribution at the entrance to the carburetor may cause
as much as 5-percent error in the measurement of air
flow by the method outlined herein. In order to take
into account any possible variation of this nature, the
carburetor is usually calibrated with the duct in place
to simulate flight conditions. Small changes in duct
design will not appreciably affect the calibration, and
carburetor duct installations that have efficient pres-
sure recovery and therefore nearly uniform pressure
distribution are almost equivalent to an ideal inlet as
far as the carburetor calibration is concerned.

FLIGHT MEASUREMENTS

The necessary measurements to determine air flow in
flight consist of absolute entrance pressure, total

entrance temperature, and boost Venturi suction. Taps
are usually provided for measurements of these pressures.
In addition to the usual carburetor-air temperature
installation, an altimeter for absolute entrance pressure
and an airspeed meter for the pressure difference are
the only equipment needed.

FUEL-FLOW MEASUREMENTS

If an indication of fuel-air ratio is desired, fuel
flow can be determined indirectly with the Bendix-
Stromberg injection-type carburetor by measurement of
the compensated air-metering pressure, inasmuch as both
the fuel-metering pressure and the effective fuel-metering
jet area are dependent upon this pressure difference.
The measurement is inadequate at low fuel flows when the
throttle is nearly closed because an additional restric-
tion in the form of a variable-area idling jet is inserted
in the fuel-measuring unit. Flight measurements, how-
ever, do not ordinarily extend into this region.

A flow-bench calibration of the carburetor is neces-
sary for translating the measurements of air-metering
pressure into fuel flow. If adequate fuel pressure
indicates that no vapor is present in the fuel system,
this measurement can be expected to give results as
accurate as the ordinary flowmeter. For greater accuracy,
a measurement of fuel temperature is desirable to take
into account a change in fuel density from that used in
calibration. The error in fuel flow due to change in
temperature is of the order of 3 percent for 100° F.

CONCLUDING REMARKS

On the basis of the calibration test described herein,
it is believed that an accurate determination of the weight
rate of air flow to the engine may be obtained in flight on
airplanes equipped with a Bendix-Stromberg injection-type
carburetor, without the necessity for insertion of an
additional measuring device in the charge-air ducts.

Langley Memorial Aeronautical Laboratory,
    National Advisory Committee for Aeronautics,
        Langley Field, Va.

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    V-1650-3 Packard-Built Engine of the North American
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2. Kinghorn, George F.: Effect of Inlet-Air Velocity
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Boost Venturi

p_2

H_1

Main Venturi
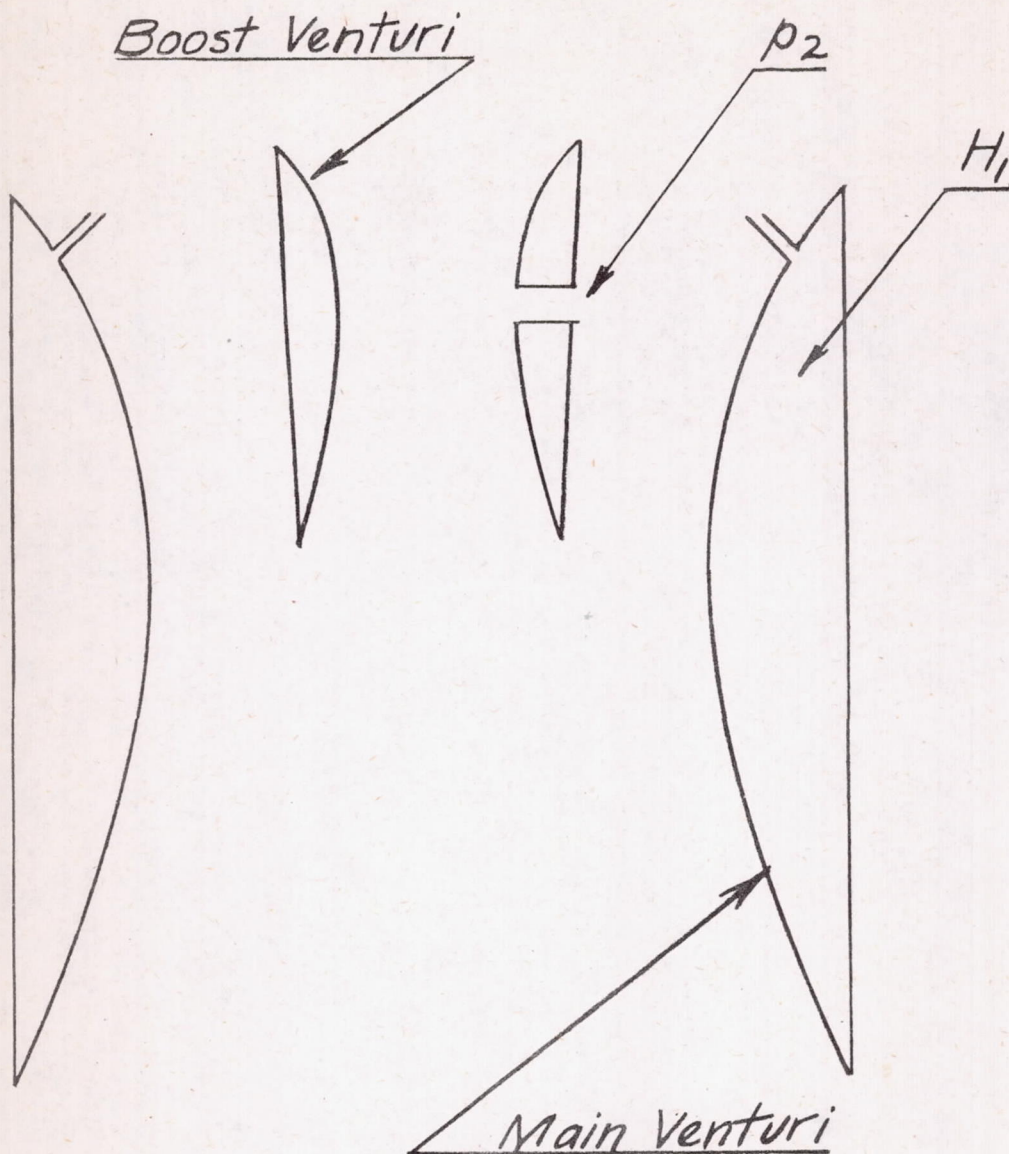
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Figure 1.- Schematic drawing of air-measuring unit
of Bendix-Stromberg injection-type carburetor.

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○ Bendix calibration
× Wright Field calibration (reference 1)

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$\dfrac{p_2}{H_1}$

p_2 absolute static pressure at boost Venturi
     throat, lb/sq ft

H_1 absolute total pressure at carburetor
     inlet (top-deck pressure), lb/sq ft

w weight rate of air flow, lb/sec

g acceleration of gravity (32.2 ft/sec^2)

ρ_1 density at inlet total pressure
     and temperature, slugs/cu ft

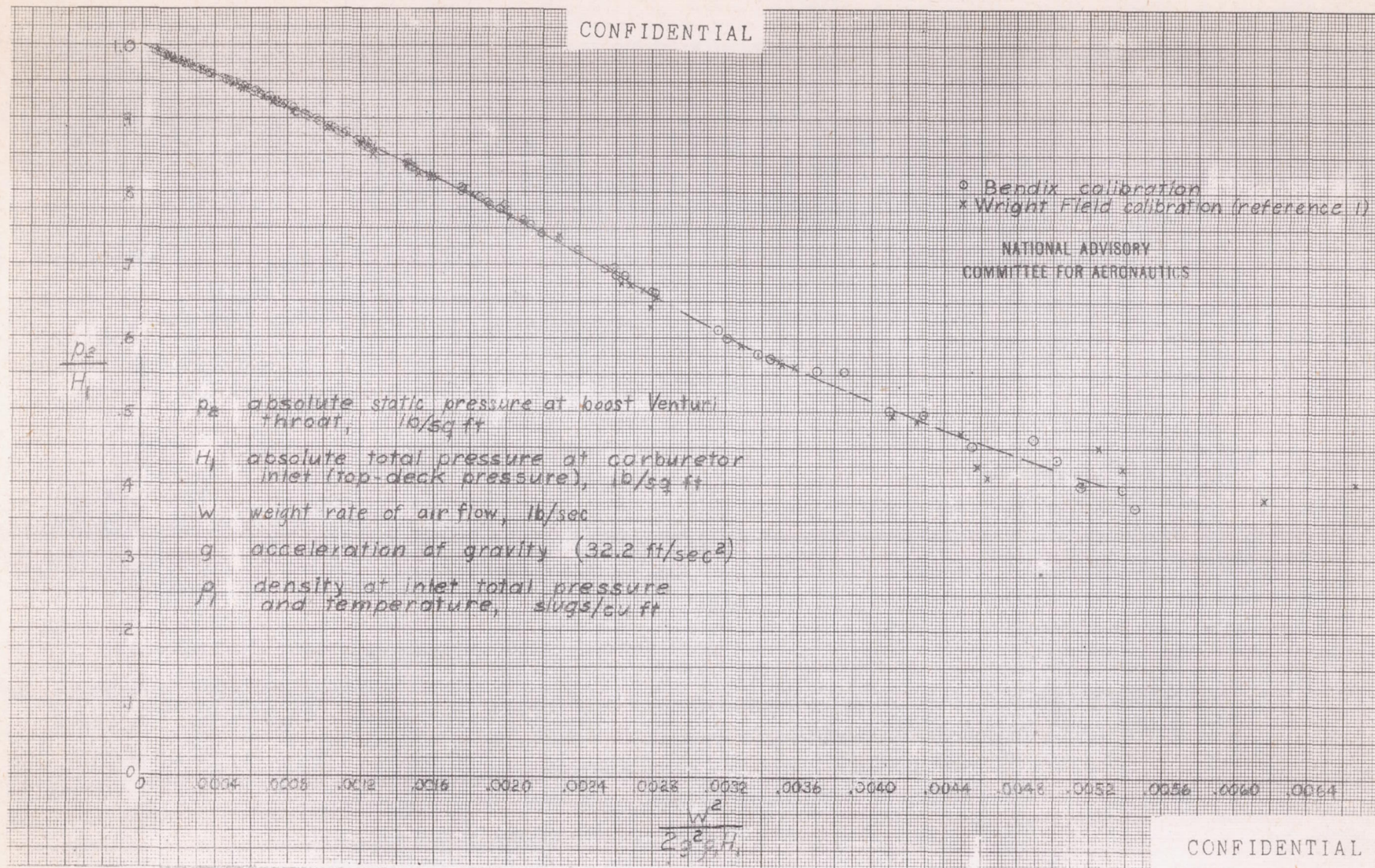$$\frac{w^2}{2g^2\rho_1 H_1}$$

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Fig. 2

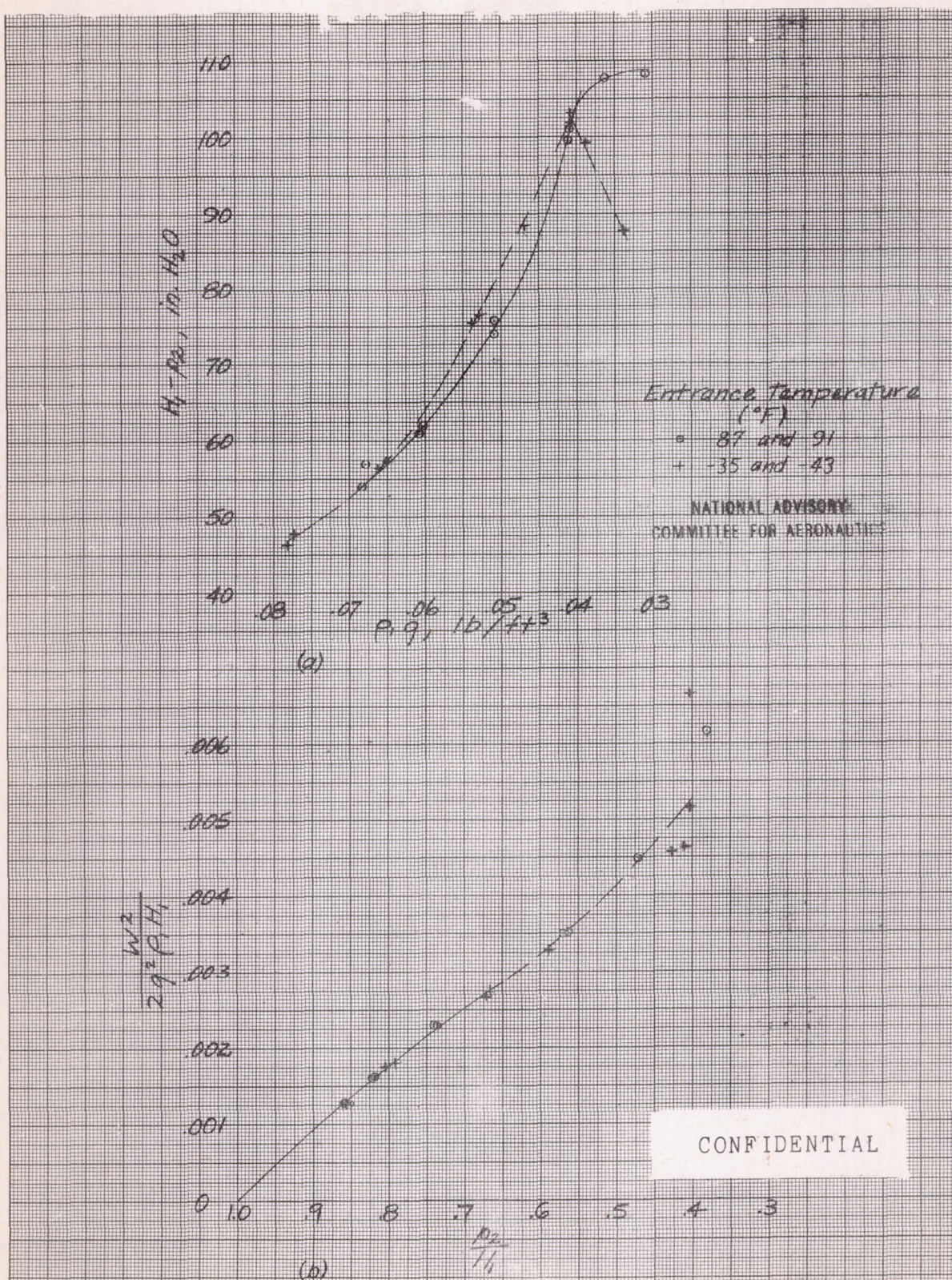Figure 2.- Typical air-flow calibration of Bendix-Stromberg injection-type carburetor.

Figure 3.- Comparison of methods of presentation of air-flow calibrations for a typical Bendix-Stromberg injection-type carburetor. W = 12,000 pounds per hour.
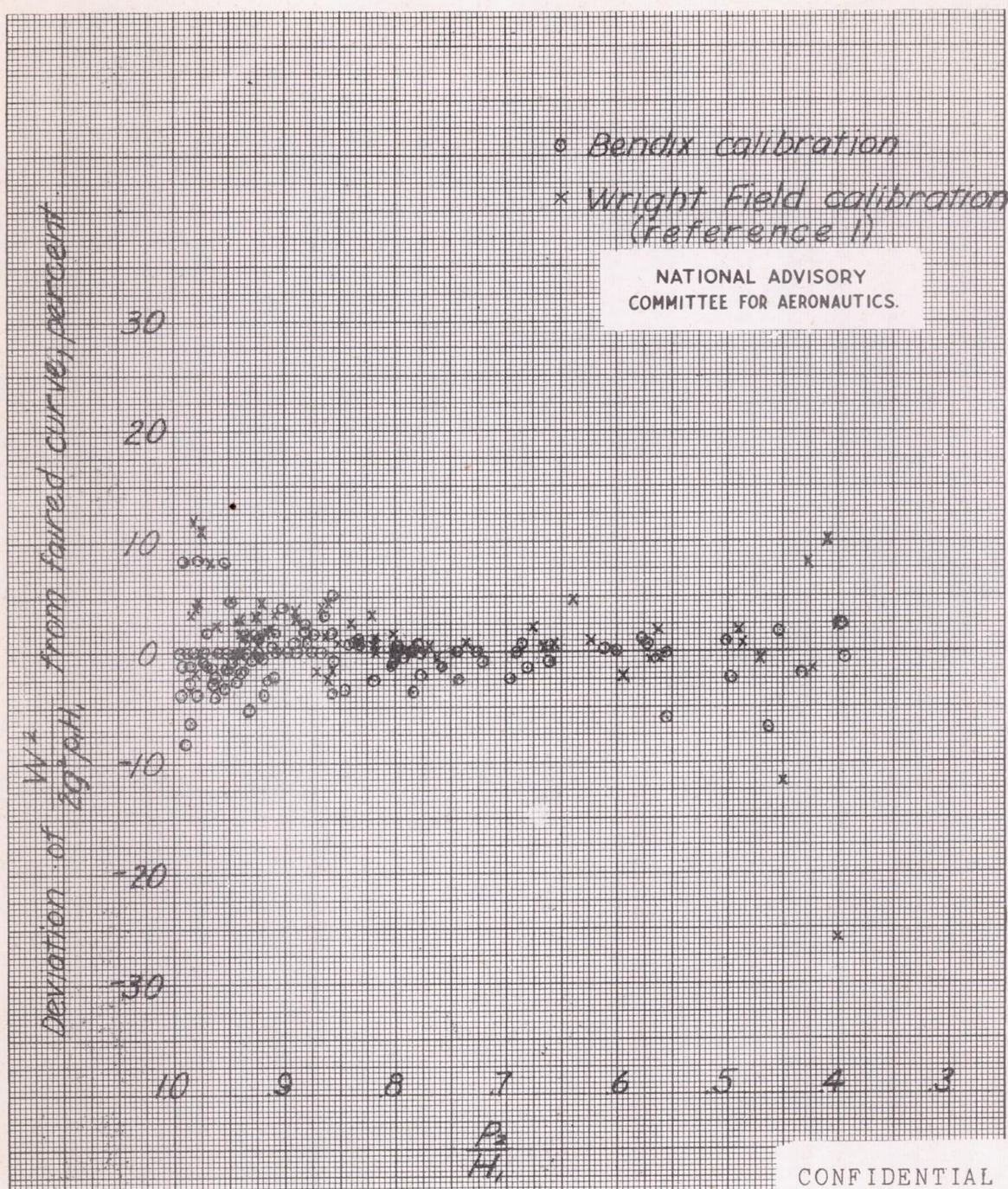
Figure 4.- Deviation of air-flow parameter from faired curve
of figure 2.